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Research on the Spatial-System-Based Rail Transit Systems of the World Cities

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Abstract

The urban rail transit system is the important basis to support the metropolitan regions of the world cities and has great significance to the formation and development of such metropolitan regions. From the perspective of relieving the urban traffic congestion, the development of rail transit requires multiple-levels and diversity; it's the key to accurately position the functions of the subway, the light rail, the suburban railway and even the national railway; then the functions should be integrated through the respective positioning and on the basis of the characteristics of different rail transit so as to give maximum play to the rail transit system. The paper dissected the basic composition, spatial layout, service objects, passenger flow scale and historical evolution of the rail transit system within the spatial system in the metropolitan regions of such world cities as Tokyo, London, New York and Paris. It compared and analyzed the main gap of Beijing's rail transit system and put forward the countermeasures and suggestions for the future development of rail transit.

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1. Introduction

Since the world's first railway came into being in Britain, different nations around the world have kept constructing the rail transit into various new systems and in myriad forms during the past over 100 years. London, Paris, New York and Tokyo formed successively, with the first densely-inhabited cities as the core -- the urban belt

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with an area of over 10,000 square kilometers, a population of ten million people, a per capita GDP of over USD 50,000 and a radiation semi-diameter of over 50-70 kilometers, and were thus renowned as the world cities [7]. Their metropolitan regions and rail transit systems formed during the 100-year urbanization and motorization provided the best reference for Beijing.

2. Analysis of the service characteristics of rail transit systems

Different ways of rail transit have their own best service semi-diameter. The traffic demand of the metropolitan regions, especially the long-distance and large-scale commuter needs with higher requirement for the motorization level and reachability, can be actually satisfied only by choosing the proper ways of rail transit in different regions and effectively linking them with other ways of rail transit.

2.1. Classification and function positioning of rail transit

According to different service objects and scope, the rail transit is classified into three categories on the urban, regional and national level, the urban railway, the regional railway (intercity railway) and the main line railway [1].The urban railway is generally located within the 100-km semi-diameter scope of the city center and mainly serves the city where it is located; the mileage of the regional railway (intercity railway) lines is generally within the scope of 100 to 400 kilometers and mainly serves the transportation between different cities in the same region; the mileage of the main line railway generally exceeds 400 kilometers and mainly serves the transportation between different regions.

The typical urban rails include the subway, the light rail and the suburban railway, etc. The subway lines are suitable for solving the traffic problem of the city central areas, especially for satisfying the need of commuting to the city central areas; if people travel for a relatively long distance and across the central areas, for example, from the north to the south and from the east to the west of the city, the light rail is more suitable for the travel need; the suburban railway is mainly used for satisfying the traffic needs [5] of the suburbs and the city central areas. Regarding the construction of the rail transit system, not only such factors as the city size, land use and fiscal capability should be considered, but also the positioning of the rail transit system and the integration of the system with other traffic means should be emphasized.

2.2. The influence of the rail transit on city development

The rail transit, as the highly-efficient, intensive and low-carbon tool of transportation, plays a supporting and guiding role [6] in the development of cities. Reasonable rail transit can optimize the spatial structure of cities, push forward the upgrading of industries, shorten the temporal and spatial distance of cities, facilitate the economic development along the rail lines and optimize the location of functional areas. In the meantime, the rail transit can accelerate the progress of land intensification and improve the city quality. The rail transit construction drives the areas along the rail lines to be newly built and transformed, guides the optimization and adjustment of the spatial layout structure of cities, promotes the development of land intensification and increases the value of the land along the rail lines. As the urban motorization progresses, problems such as traffic congestion as well as air and noise pollution are getting increasingly severe. According to related researches, the energy consumption of the rail transit with equivalent transport capacity equals to the one ninth of the energy consumption of cars and one half of that of buses, and the rail transit with equivalent transport capacity has more obvious advantages in the aspects of carbon dioxide emission and noise [4].

Take Tokyo Tama New Town and Chiba New Town for example. In the 1970s, Tokyo tried to relieve traffic congestion by constructing new towns. The Tama New Town and Chiba New Town built in the same period achieved different results due to the differences in the construction and operation of the rail transit. In the Tama New Town, three suburban railways were opened and convenient connection was established from the New Town to the city center. Therefore, a size of 160,000-people population had been formed by the early 1990s. While in the Chiba New Town, the rail transit had no connected lines throughout the city and no line led directly to the city center of Tokyo, so the inhabited population grew slowly.

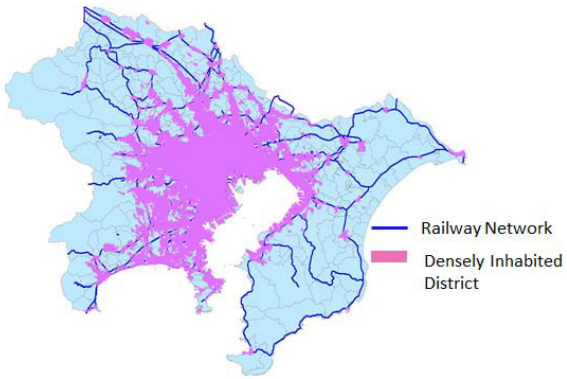

Fig. 1. The Densely Inhabited District and Railway Network of Tokyo Metropolitan Region

3. Dissection of the rail transit systems of metropolitan regions in world cities

An in-depth observation of the metropolitan regions in world cities can reveal that the public transportation, especially the rail transit systems, is the basis for supporting the highly-efficient operation of the metropolitan regions in world cities [2].

3.1. The rail transit system of the Tokyo metropolitan region

The Tokyo metropolitan region is consisted of Tokyo Metropolis and the surrounding three prefectures, Kanagawa, Saitama and Chiba, covering an area of 13,400 km² and having a population of 35 million people, and is the metropolitan region with the largest population in the world [3]. The Tokyo rail network is composed of the subway, the national railway, the private railway and the Shinkansen high speed railway. The national railway is operated by East Japan Railway Company with an operated mileage of 887 kilometres and daily passenger volume of 14.96 million people; the subway is operated by Tokyo Metro and Toei Subway with an operated mileage of 333 kilometres and daily passenger volume of 11.03 million people; the private railway is operated by Tokyo Corporation, Tobu Railway Co., Ltd., Odakyu Electric Railway Co., Ltd., Keio Corporation, Seibu Railway Co., Ltd., Keikyu Corporation, Keisei Electric Railway Co., Ltd., and Sagami Railway Co., Ltd., 8 companies in total, with an operated mileage of 1,086 kilometres and daily passenger volume of 13.31 million people.

- The core area (5 km semi-diameter): It takes the Tokyo Station as the center of a circle, including the internal and surrounding adjacent areas of the Yamanote railway loop line (a total length of 34 km) and covering an area of approximately 90 km². Here located are the central area and the five sub-central areas (7 in total) of the Tokyo metropolitan region, Shinjuku, Shibuya, Ikebukuro, Osaki and Ueno. Over 80% of the subway lines in Tokyo are distributed in this area.
- The central area (15 km semi-diameter): It is consisted of 23 districts which are under the jurisdiction of Tokyo Metropolis and also called the Tokyo Metropolis region or the Tokyo Metropolis 23 region with an area of 622 km². Apart from the subway, multiple JR national and private railway lines are also distributed in this area.
- The inner suburbs (30 km semi-diameter): It is consisted of the Tokyo Metropolis Tama area and the areas of three prefectures near Tokyo Metropolis. The Tama New Town of Tokyo Metropolis, Yokohama and Kawasaki of Kanagawa Prefecture and Haneda Airport all belong to this area. This area is served by JR national railway and private railway.
- The outer suburbs (70 km semi-diameter): It is the peripheral area of the Tokyo Metropolis region. The Narita International Airport is located in this area. It is mainly served by the JR national railway and a small amount of private railway lines.

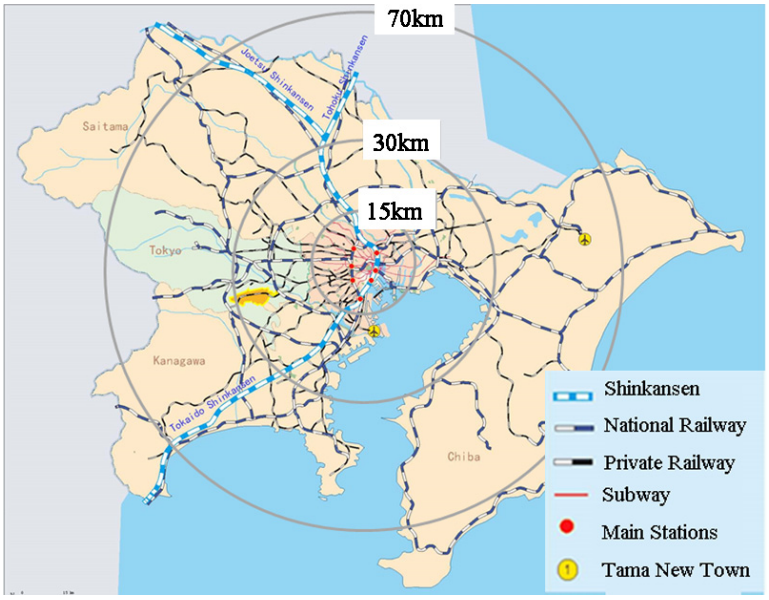

Fig. 2. The Rail Transit Systems of the Tokyo Metropolitan Region

The subway, the suburban railway (national and private railway) and the Shinkansen high speed railway of the Tokyo metropolitan region are linked seamlessly through the Yamanote railway loop line of the Tokyo central region. The subway mainly serves the areas within and the core areas near the Yamanote railway loop line and the central areas consisted of 23 districts. The suburban railway mainly serves the urban areas outside the Yamanote railway loop line. The five Shinkansen high speed railway lines starting from the Tokyo railway station on the Yamanote line connect such major cities as Osaka and Nagoya, actualizing the daily round trip between these cities and the main commercial districts of Tokyo.

3.2. The rail transit system of the London metropolitan region

The London metropolitan region, with Inner London as the core, includes the main cities in Greater London and Southeast England with a total area of 25,000 km² and a population of 17 million people [3].

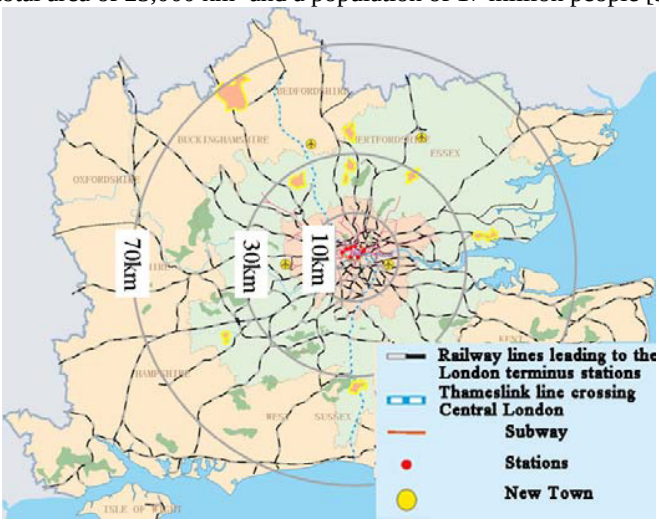

Fig. 3. The Rail Transit System of the London Metropolitan Region

- The core area (5 km semi-diameter): It is a small area within the Inner London Subway loop line (27 km) and on the southern bank of the Thames nearby. This is the area mainly served by London Metro. The 27-km² London Congestion Charge Zone is located in this area.
- The central area (10 km semi-diameter): It is the Inner London consisted of 12 districts which belong to London, covering an area of 321 km².
- The inner suburbs (30 km semi-diameter): It is the area encircled by the peripheral M25 expressway (188 km) of London. The London Heathrow International Airport is located in this area.
- The outer suburbs (70 km semi-diameter): The Southeastern areas of Britain centering London include 12 areas, such as Oxford shire, County of Kent, Berkshire County and Buckinghamshire. The London Milton New Town is right here.

The rail system of the London metropolitan region is composed of the subway system and the suburban railway system which link through such main railway stations as the King's Cross Railway Station and the St. Pancras railway station in the city center. The subway system mainly serves the city of London, and the suburban railway system serves the new towns and the outer suburbs. The high speed railway links through the railway station in the London center, crosses throughout the London center and connects with Paris and Brussels, etc.

3.3. The rail transit system of the Paris metropolitan region

The Paris metropolitan region is consisted of Paris and its three surrounding provinces in the inner suburbs and four provinces in the outer suburbs. It is called Paris Region or Island of France, covering an area of 12,000 km² and having a population of 11.69 million people [3].

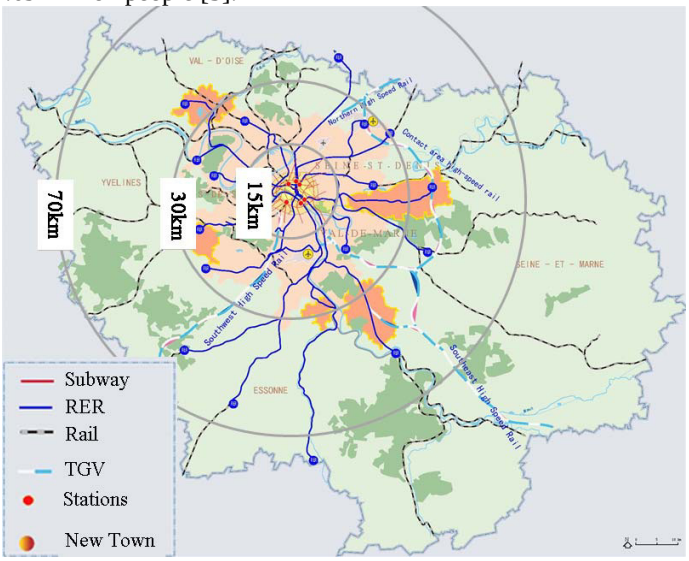

Fig. 4. The Rail Transit System of the Paris Metropolitan Region

- The core area (5 km semi-diameter): It mainly refers to the area within Paris with an area of 105 km² where 80% of the Paris subway lines are distributed. Additionally, the important traffic hub gathering the subway, RER, the suburban railway and the high speed railway are located in this area.
- The central area (15 km semi-diameter): It mainly refers to Paris and the surrounding Hauts-de-Seine, Senna-Saint-Denis and Marne-la-Vallée, covering an area of 768 km². The famous La Défense is right here in this area.
- The inner suburbs (30 km semi-diameter): This area includes five new towns, such as Marne-la-Vallée and Senna, etc., which is also the main service scope of RER. The Charles de Gaulle International Airport and Orly International Airport are situated in this area as well and connected with the core area of the metropolitan region via RER lines.

- The outer suburbs (70 km semi-diameter): It's consisted of four provinces in the outer suburbs of Paris Region, including Essonne, Val-de-Marne and Seine-et-Marne, etc. The areas are connected mainly through the suburban railway.

The rail transit system of the Paris metropolitan region is consisted of the subway, the RER, the suburban railway and the high speed railway (TGV), which are linked seamlessly through the six major railway stations in the central area of Paris. The subway system mainly serves Paris; the RER system serves the inner suburbs and new towns; and the TGV system serves the provincial and even international areas.

3.4. The rail transit system of the New York metropolitan region

The New York metropolitan region includes New York City and the surrounding 23 counties of three states, New York, New Jersey and Connecticut, covering a total area of 23,500 km² and having a population of nearly 22 million people [3].

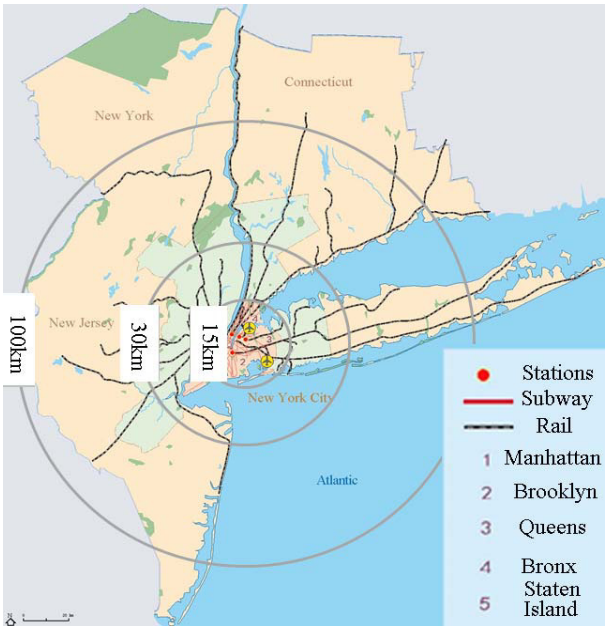

Fig. 5. The Rail Transit System of the New York Metropolitan Region and the Comprehensive Hub Layout

- The core area (5 km semi-diameter): Manhattan District, covering an area of 59 km², is the area with the densest subway lines in New York.
- The central area (15 km semi-diameter): It is consisted of five districts: Manhattan, Bronx, Brooklyn, Queens and Staten Island, covering an area of 789 km².
- The inner suburbs (30 km semi-diameter): It includes part of the administrative districts (such as Hudson, Essex) outside the central city and part of the areas in New Jersey, covering a total area of about 3,000 km². The John F. Kennedy International Airport, the La Guardia Airport and the Newark Airport are right here in this area.
- The outer suburbs (70 km semi-diameter): It includes the prefectures in the outer suburbs of State of New York, Connecticut, New Jersey and Long Island.

The rail transit system of the New York metropolitan region includes the subway, the regional express railway and the suburban railway. The subway and regional express railway mainly serve the city of New York. The suburban railway system is consisted of three main parts, the Long Island Railroad, the New York Metro-North Railroad and the New Jersey Railroad which mainly serves the inner and outer suburbs and actualizes the seamless transference with the subway system via the six major railway stations.

4. A new review of Beijing from the perspective of world big cities

As shown by the dissection of the Beijing rail transit system and the comparison with the rail transit systems of the world cities, the rail transit of Beijing still lags behind in the aspects of the scale, level, planning and layout, etc.

4.1. The overall introduction of the city development of Beijing

In 2010, the comprehensive transportation system of Beijing met the travel demand of 19.61 million people, 53.83 million people per day and 41.30 million people within the Sixth Ring Road [8]. The commuter circle was expanded from the 15-km semi-diameter fifth ring scope to the 30-km semi-diameter. The latest traffic survey of world cities revealed that, corresponding to the population size, the daily travel needs of the Paris, London, New York and Tokyo metropolitan regions were 35.16 million people, 48.6 million people, 59.6 million people and 84.33 million people respectively, 0.65, 0.9, 1.1 and 1.6 times more than that of Beijing .

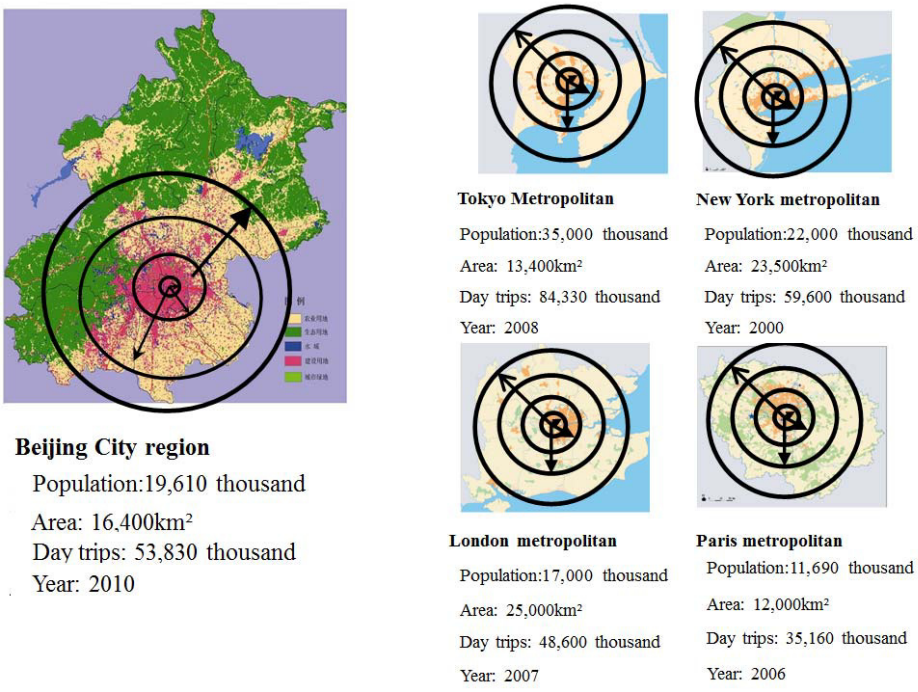

Fig. 6. Comparisons between Beijing Metropolitan Region and Metropolitan Regions of World Big Cities

4.2. The gap of the Beijing rail transit system

Compared with world cities, the subway, suburban railway and high speed railway of Beijing are relatively independent and cannot constitute an organic integrity to serve the different areas of the city. There is still a big gap between the overall transport capacity of the Beijing rail system and that of world cities, which is specifically shown in the following aspects:

- The subway: Compared with world cities, the Beijing Subway has an overly large service area; the density of the core area is lower; the connection with the new town is not efficient and the transport capacity is restricted.
- The railway: The railway of Beijing hasn't actually served the city. More suburban railway lines are planned to open, but improvement is required in many aspects, for example, the setting of the lines, the selection of the station locations, the fare system and fares as well as the service patterns.

- The intercity high speed railway: Compared with world cities, the intercity high speed railway of Beijing has merely fulfilled the intercity transportation services between railway stations. Whereas in the world cities, the highly efficient transportation services are provided by directly combining the intercity high speed railways with the urban functional areas and integrating the intercity transportation and the transportation within the city. Therefore, the gap is relatively large.

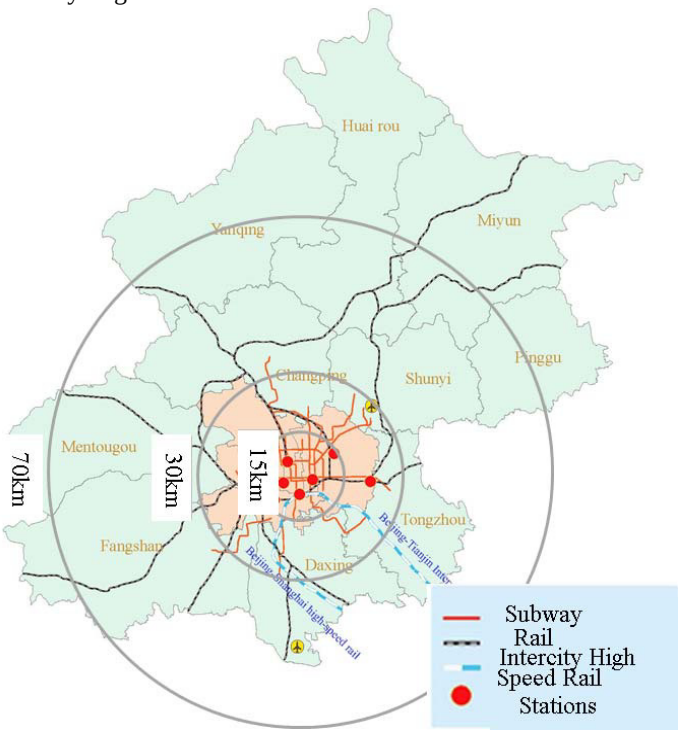

Fig. 7. The Rail Transit System of Beijing City

4.3. Inspiration for the development of Beijing's rail transit

Currently Beijing is moving towards its goal to be a world city. On one hand, its population size will continue to grow and the commuter semi-diameter will extend continuously, but the existing urban transportation system cannot bear the heavy burden; on the other hand, the high-end travel demand for the high speed railway and the intercity rapid rail increases day by day, but the urban functional layout is separate from the railway hub, making it difficult to satisfy the diverse high-end travel needs. Tokyo and Beijing are both Asian cities. The rail transit system of the Tokyo metropolitan region and the spatial layout of its comprehensive hub serve as a significant reference for the future development of Beijing City and its traffic. Therefore, Beijing can strive in the following several aspects:

- It should straighten out the relationships properly and construct a multiple-level urban railway system

It should rely on the urban comprehensive traffic hub, build a reasonable rail transit system and straighten out the relationships among various traffic means to make them serve their purposes. For example, the subway serves the areas with high-density and high-intensity travel in the city center; the suburban railway serves the suburban areas with a large scope and large transport volume; the seamless connection can be achieved via the comprehensive traffic hub.

- It should emphasize the time sequence of city development and rail transit construction and carry out the railway-based high-intensity land development

As for the urban rail system represented by the railway hub, a very important function is to promote the intensive utilization of land and the comprehensive development of the surrounding land. Through the railway-based high-

intensity land development, the regional land value will be increased, the economy will be driven to develop and meanwhile the unnecessary traffic needs will be reduced.

- It should improve the operation efficiency of the urban rail transit by connecting the different railway lines (the direct connection service) or operating the lines parallel on the basis of the railway hub

For passengers, the commuting time should be reduced without transference, ticket affairs or walking but with relieved congestion of the transportation and hub. For the suburban railway operators, it's important to reduce the time and distance when people travel to the city center; concurrently, the areas along the railway lines should be developed to increase the demand. The traffic tools and employees are utilized less and less during operation and the congestion in the city central hub areas is relieved. For the railway operators, the demand increases and the railway factory stations available in the suburbs can be added. The cost is high if they are constructed and maintained under the ground.

- The privately-operated railway (the private railway) pushes forward the development of the railway and residential houses in the metropolitan suburbs

The construction of rail transit and the high-density development of stations require continuous impetus and substantial capital investment. However, the shortage of funds always becomes an important difficulty facing the urban construction and development: on one hand, the financial gap is large, which leads to the overly heavy fiscal burden on the government. Therefore, the government always considers the cost during construction and constantly reduces the construction size with no transcendent consciousness; on the other hand, this phenomenon conversely further results in the insufficient impetus for sustainable development, which forms a vicious circle to severely hinder the construction and development of the city. The different cities around the world, while promoting the development of rail transit, attach great importance to the diverse patterns of rail transit investment; the diverse investment patterns will drive the development patterns of the city.

5. Conclusion

The paper mainly studied the four world cities, Tokyo, London, New York and Paris. It analyzed the composition and services of the rail transit systems of these cities. Meanwhile it dissected in depth the current problems and gap of the Beijing rail transit system and proposed the suggestions for the future development of the Beijing rail transit. The main conclusions are shown as follows:

- The rail transit system is the basis to support the highly-efficient operation of the metropolitan regions in world big cities. The prerequisite for satisfying the large-scope, large-scale, different and individualized traffic needs of the metropolitan regions is to establish an improved and reasonable rail transit system and an intensive and highly-efficient comprehensive traffic hub. Beijing is the capital of China with a large population of 1.3 billion people. Its population growth and traffic demand scale are probably close to or even exceed those of the Tokyo metropolitan region. Therefore, it's a necessary path to construct the reasonable rail transit system and highly-efficient comprehensive hub in order to meet the future greater population size and the traffic demand scale with the 50-km commuter semi-diameter.
- Right now the Beijing rail transit system does not match its urban development to some extent. Beijing should depend on the urban comprehensive traffic hub, build a reasonable rail transit system and straighten out the relationships among various traffic means to make them serve their purposes properly.

Acknowledgements

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